DESIGN AND SIMULATION OF TRI-BAND OMNIDIRECTIONAL MICROSTRIP PATCH ANTENNA FOR WI-FI 7 APPLICATIONS

Dissertation submitted to
Visvesvaraya National Institute of Technology, Nagpur
in partial fulfillment of the requirements for the award of the degree

MASTER OF TECHNOLOGY
in
COMMUNICATION SYSTEM ENGINEERING

by
Komal Durvas Kamble
MT23CMN007

Under the guidance of:

Dr. Punit Bhavsar
Assistant Professor
VNIT, Nagpur

Department of Electronics and Communication Engineering
Visvesvaraya National Institute of Technology, Nagpur
Nagpur 440010 (India)
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DEPARTMENT OF ELECTRONICS COMMUNICATION ENGINEERING

VISVESVARAYA NATIONAL INSTITUTE OF TECHNOLOGY, NAGPUR

DECLARATION

I, **Komal Durvas Kamble** hereby declare that this dissertation titled **"Design and Simulation of Tri-Band Omnidirectional Microstrip Patch Antenna for Wi-Fi 7 Applications"** is carried out by me in the **Department of Electronics and Communication Engineering**, of Visvesvaraya National Institute of Technology, Nagpur.The work is original and has not been submitted earlier whole or in part for the award of any degree/diploma at this or any other Institution/University.

Komal Durvas Kamble
Date:

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
VISVESVARAYA NATIONAL INSTITUTE OF TECHNOLOGY, NAGPUR

CERTIFICATE

This is to certified that the dissertation titled **"Design and Simulation of Tri-Band Omni-directional Microstrip Patch Antenna for Wi-Fi 7 Application."** is submitted by **Komal Durvas Kamble** in partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Communication System Engineering**, VNIT Nagpur. The work is comprehensive, complete and fit for final evaluation.

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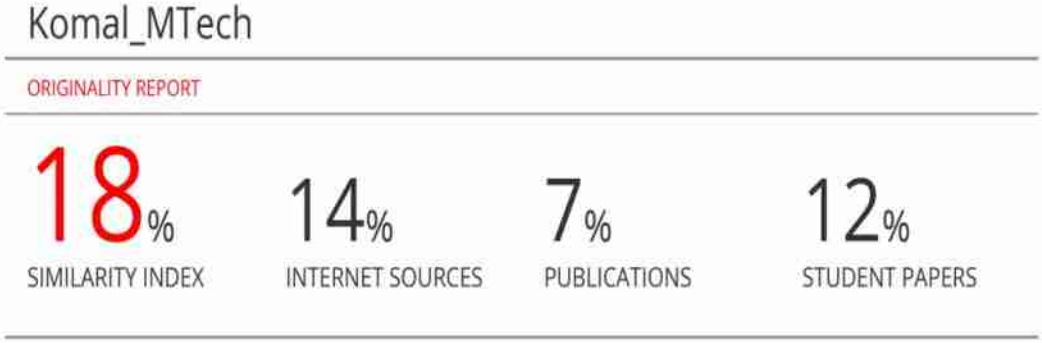

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ACKNOWLEDGMENT

I would like to express my sincere gratitude and appreciation to all those who have helped with the completion of my thesis work. Without their support, guidance, and encouragement this achievement would not have been possible. Firstly, I would like to extend my heartful thanks to my supervisor **Dr Punit Bhavsar**, Assistant Professor in the Department of Electronics & Communication Engineering at VNIT Nagpur, for their invaluable guidance throughout the research process. I am truly grateful for their insightful feedback, constructive criticism and continuous motivation which has greatly enhanced the quality of this thesis. I am also grateful to the faculty members and staff of VNIT. I would like to extend my appreciation to all the professors, instructors, researchers, PHD candidates who have contributed to my academic journey.

I am also grateful to my Internship Manager, **Mr. Akshaya Mishra** at NXP Semiconductors, for providing me with the tools and ideas to work with, as well as for their continuous support throughout the thesis process.

10th June 2025 ***Komal Durvas Kamble***

ABSTRACT

This study presents the design and simulation of a tri-band omnidirectional microstrip patch antenna tailored for Wi-Fi 7 systems. The antenna operates effectively within the 2.4 GHz and 5-7.125 GHz frequency bands and was meticulously designed using High Frequency Structure Simulator (HFSS). Constructed with FR-4 material, the antenna dimensions are 52 x 13 x 1.6 mm. Performance metrics revealed a return loss of -24.22 dB at 2.5 GHz, -47.25 dB at 5.5 GHz, and -55.90 dB at 6.9 GHz, with a Voltage Standing Wave Ratio (VSWR) of less than 2 across all bands. The radiation pattern is omnidirectional, ensuring consistent gain, making the antenna ideal for both indoor and outdoor Wi-Fi 7 routers. System-level performance was evaluated by integrating the antenna into a Wi-Fi transceiver, analyzing its impact on data rate, coverage, and signal quality. The results underscored the antenna's capability to support high-speed wireless communication with robust performance in diverse environments, positioning it as a promising solution for next-generation Wi-Fi applications.

Keywords: Microstrip patch antenna,Wi-Fi 7 return loss, tri-band, Omni-directional

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LIST OF ABBREVIATIONS

HFSS	High Frequency Structure Simulator
GPS	Global Positioning System
MPA	Microwave Patch Antenna
VSWR	Voltage Standing Wave Ratio
TEM	Transverse Electromagnetic
IEEE	Institute of Electrical and Electronics Engineer
MIC	Microwave Integrated Circuits
MMIC	Monolithic Microwave Integrated Circuits
EBG	Electromagnetic Band Gap
UHF	Ultra High Frequency
SAR	Synthetic Aperture Radar
MWA	Microwave Ablation
VNA	Vector Network Analyzer
PCB	Printed Circuit Board
FEM	Finite Element Method
PEC	Perfect Electric Conductor
PML	Perfect Matched Layer

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CHAPTER I

INTRODUCTION

1.1 Background And Motivation

The rapid evolution of wireless communication technologies has led to the emergence of Wi-Fi 7, also known as IEEE 802.11be. This new standard aims to meet the increasing demand for higher data rates, lower latency, and improved reliability, driven by applications such as 4K/8K video streaming, virtual reality (VR), augmented reality (AR), and real-time online gaming. Wi-Fi 7 introduces several enhancements over its predecessors, including support for wider channel bandwidths up to 320 MHz, higher-order modulation schemes like 4096-QAM, and Multi-Link Operation (MLO) that allows simultaneous transmission across multiple frequency bands**[1]**.

These advancements necessitate the development of antennas capable of operating efficiently across multiple frequency bands, particularly the 2.4 GHz, 5 GHz, and 6 GHz bands. Designing such antennas poses challenges in terms of achieving broad bandwidth, maintaining omnidirectional radiation patterns, ensuring high gain, and accommodating compact form factors suitable for integration into modern devices like laptops, smartphones, and routers**[2]**.

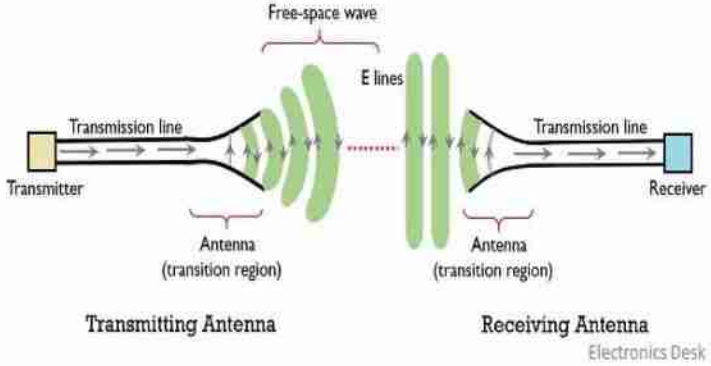


Figure 1.1: Signal transmission through antenna

The continuous introduction of new wireless devices has driven a growing demand for compact antennas. Additionally, the growth in satellite communication and the use of antennas in aircraft and spacecraft have heightened the need for low-profile antennas that ensure reliable communication.

1.2 Literature Review

Recent research efforts have focused on developing antenna designs that cater to the requirements of Wi-Fi 7. For instance, Murata Manufacturing Co., Ltd. introduced a parasitic element coupling device that enhances antenna efficiency by magnetically coupling parasitic elements with the main antenna, facilitating compact and efficient designs suitable for space-constrained devices**[2]**.

In another study, a compact asymmetric T-feed closed-slot antenna was proposed for 2.4/5/6 GHz Wi-Fi 7 MIMO laptop applications. This design achieved dual-band operations covering the 2400–2500 MHz and 5150–7125 MHz bands, with measured isolation greater than or equal to 10 dB and radiation efficiency exceeding 64% **[3]**.

Additionally, a low-profile tri-band MIMO antenna system was developed, utilizing a loaded Planar Inverted-F Antenna (PIFA) with unique slots to cover the 2.4 GHz, 5 GHz, and 6 GHz bands. The design demonstrated excellent RF characteristics, making it suitable for Wi-Fi 7 applications requiring wider channel bandwidths and higher throughput rates **[4]**.

1.3 Fundamentals of Antenna

An antenna is a vital part of wireless communication systems, acting as a device that converts electrical signals into electromagnetic waves and vice versa. It acts as a bridge between the transmission line and free space, enabling the transmission and reception of radio waves. The characteristics of antennas include radiation pattern, radiation efficiency, gain, input impedance, bandwidth, and polarization. Diverse types of antennas are used based on the specific needs of each application which includes wire antennas, array antennas, reflector antennas, microstrip antennas, horn antennas, and Yagi-Uda antennas. The radiation mechanism involves the transmission of the electromagnetic field generated by the source through the transmission line to the antenna system, which then radiates it into free space.

Antennas are used in numerous systems, including communication systems (cellular phones, satellite communications, and wireless networks), remote sensing (weather monitoring), radar systems (detecting and tracking objects), and biomedical applications (medical imaging and diagnostics). Understanding these fundamentals is essential for designing efficient and effective antennas for diverse applications, ensuring reliable and high-performance wire-

less communication.

1.3.1 Radiation Pattern

The radiation pattern, also known as the Antenna Pattern or Far-Field Pattern, is a crucial concept in antenna design. It graphically represents the radiated power at a fixed distance from the antenna, depicted as a function of azimuth and elevation angles. The radiation pattern can be shown in a 2D plane for different azimuth and elevation angles, referred to as the azimuth plane pattern and elevation plane pattern. It is often useful to plot these radiation patterns in Cartesian (rectangular) coordinates, especially when the antenna radiation pattern includes various side lobes, as the levels of these side lobes can be significant. Below are descriptions of several types of antenna patterns.

Omnidirectional Antenna

An omnidirectional antenna is one that has a uniform radiation pattern, distributing energy equally in one plane, typically the horizontal plane. This type of antenna is ideal for applications such as mobile phones, FM radios, walkies-talkies, wireless computer networks, cordless phones, GPS, many portable handheld devices, and base stations, where consistent coverage in all directions is needed. The radiation pattern of an omnidirectional antenna is described as doughnut shaped. Examples of low-gain omnidirectional antennas include slot antennas, dipole antennas, whip antennas, and duck antennas. High-gain omnidirectional antennas can be designed by narrowing the beam width in the vertical plane, which concentrates energy in the horizontal plane. Consequently, a narrow beam width results in higher gain, and distinct types of omnidirectional antennas with different gains can be designed.

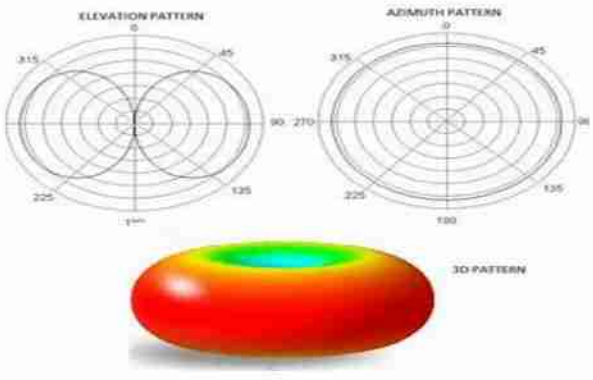


Figure 1.2: Omnidirectional Radiation Antenna

Directional Antenna

Directional antennas, as the name implies, focus their radiation on a specific direction. Also known as beam antennas, they are useful for point-to-point applications like satellite communication and for base stations to transmit energy within a particular sector. Examples of antennas with directional radiation patterns include Yagi antennas, horn antennas, log-periodic antennas, and panel antennas.

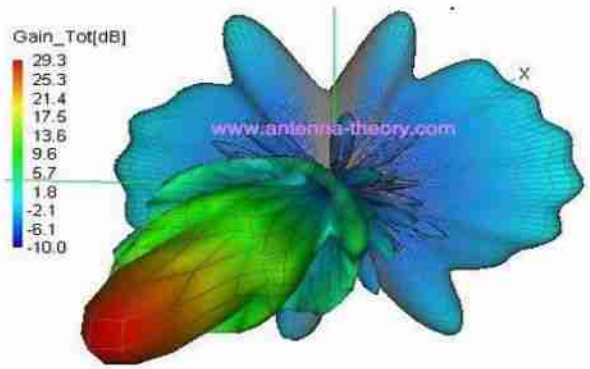


Figure 1.3: Directional Radiation Antenna

Isotropic Antenna

An isotropic antenna is a theoretical model that emits electromagnetic energy equally in all directions. It radiates the total input power uniformly across a spherical pattern. Although such an antenna doesn't exist in reality, it serves as a standard reference for evaluating the performance of real-world antennas.

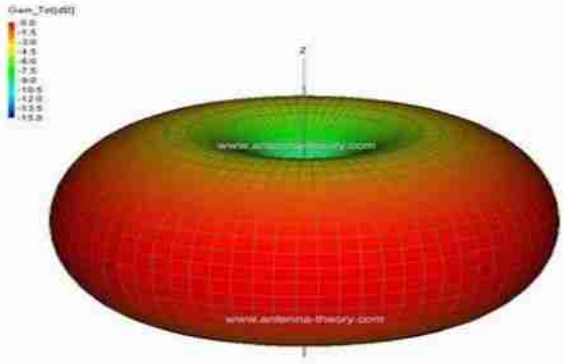


Figure 1.4: Isotropic Radiation Antenna

1.3.2 Field Region

Antennas have different field regions that describe how electromagnetic fields behave at various distances. Close to the antenna is the near-field (Fresnel) region, which includes

the reactive near-field where energy is stored rather than radiated, and the radiative near-field where the fields start to radiate but are still complex. Further away is the far-field (Fraunhofer) region, where the fields stabilize into a predictable pattern with electric and magnetic fields forming plane waves. Understanding these regions helps in predicting how an antenna will perform in different situations.

$$R = \frac{2D^2}{\lambda}$$

Where, R = distance from antenna

D = larger dimension of antenna

λ = wavelength in free space

1.3.3 Directivity

Directivity is a critical parameter in antenna theory, representing the ability of an antenna to focus radiated power in a specific direction. This measure is essential for applications requiring precise targeting of signals, such as satellite communications and radar systems, where high directivity enhances signal strength and minimizes interference from other directions. Directivity in its simple form can be described as the comparison of maximum radiation intensity to average radiation intensity. As

$$\text{Directivity} = \frac{\text{maximum radiation intensity}}{\text{average radiation intensity}}$$

Directivity measures how concentrated an antenna's radiation pattern is. An antenna with high directivity produces a sharp, concentrated beam, much like a flashlight that directs its light into a narrow, intense stream. Conversely, an antenna with low directivity spreads energy more evenly in all directions. This characteristic is crucial for optimizing communication system performance, ensuring efficient signal transmission and reception.

1.3.4 Antenna Gain

Antenna gain is a key parameter that combines the directivity and efficiency of an antenna. It measures how well an antenna converts input power into radio wave in specific direction, compared to a hypothetical isotropic antenna that radiates equally in all directions. The gain

usually expressed in decibel (dB). The gain of an antenna is given by:

$G = \eta \cdot D$

Where,

G is the gain

η is the efficiency of the antenna

D is the directivity

Higher gain indicate that the antenna can transmit or receive signal more effectively in a particular direction, making it crucial for application like satellite communication, radar, and wireless networks. High gain antenna is designed to focus energy on specific direction, thereby improving signal strength and reducing interference from unwanted direction.

1.3.5 Antenna Polarization

Antenna polarization describes the direction in which the electric field of an emitted electromagnetic wave is oriented. It plays a vital role in antenna design and functionality, influencing the efficiency of signal transmission and reception. The main types of polarization include linear, circular, and elliptical:

- Linear Polarization – The electric field remains confined to a single plane, which may be either vertical or horizontal.
- Circular Polarization – The electric field rotates in a circular pattern as the wave travels, and it can be either right-hand or left-hand circular.
- Elliptical Polarization – This is a more general form where the electric field traces an elliptical path, blending characteristics of both linear and circular polarization.

1.3.6 Antenna Bandwidth

Antenna bandwidth is a key characteristic that defines the span of frequencies over which the antenna operates effectively, maintaining its intended performance standards. Bandwidth can be described based on gain, axial ratio bandwidth, impedance or VSWR. Impedance bandwidth is the range of frequencies where an antenna's input impedance matches the characteristic impedance of the transmission line feeding it. When discussing impedance bandwidth in relation to the Q factor, it refers to how efficiently the antenna can operate over a range

of frequencies without significant loss or mismatch. Fractional bandwidth describes the fre-

$$\text{BW} = \frac{s-1}{Q_T\sqrt{S}} \qquad \text{(VSWR S: 1)}$$

quency range over which a microstrip antenna operates effectively. Where fh and fl are the

$$BW = \frac{f_h - f_l}{fc}$$

upper and lower frequencies where the VSWR matches to S:1. Typically, a VSWR (Voltage Standing Wave Ratio) of 2:1 is considered acceptable, but the ideal value is 1:1. To maximize the impedance bandwidth for VSWR 2:1 proper impedance matching is required. That is, we must feed at the driving point where antenna impedance is Zo = 50 ohm. One can get a little bit more bandwidth by feeding at the point where the antenna impedance is 65 ohms.

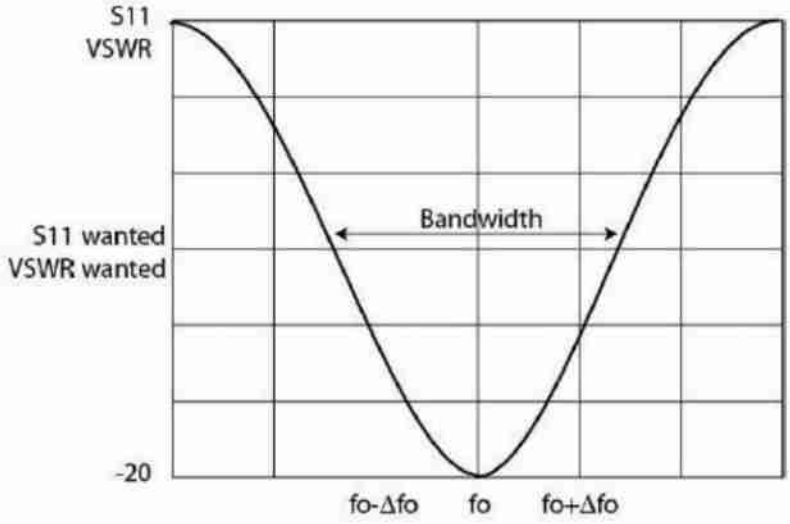


Figure 1.5: Bandwidth of Antenna

CHAPTER II

LITERATURE REVIEW

2.1 Research Paper Review

Ref.	Title	Author	Workdone
[1]	Design of 2.4 GHz and 5.8 GHz Microstrip Antenna on Wi-Fi Network	L. M. Silalahi, S. Budiyanto, F. A. Silaban, I. U. V. Simanjuntak, P. S. Hendriasari and Heryanto	A dual-band microstrip antenna with a trident shape, specifically for Wi-Fi use at 2.4 GHz and 5.8 GHz by using CST simulation software**[6]**.
[2]	Rectangular Patch, U and H Slot Triple Band Antenna for Different Wireless Applications	D. Pandey, A. Dogra, and S. Kundu	Triple-band rectangular patch antenna with microstrip line feed and a partial ground plane, designed on a low-cost FR4 substrate. The design includes U- and H-shaped slots and an extra strip to achieve multiple resonances, while the partial ground enhances low-frequency bandwidth**[7]**.
[3]	A High Gain Omnidirectional Dipole Array Antenna for WiFi-6E	W. Gu, B. Feng, Y. Luo, X. Zhu, and Y. Lu	High-gain omnidirectional dipole array antenna for WiFi-6E (5.925–7.125 GHz), using eight double U-shaped dipoles to achieve strong, uniform radiation and efficient performance**[8]**.
[4]	An Omni-directional Antenna with High Gain for WiFi-6 Applications	B. Yang, H. Huang, B. Feng, and L. Deng	Omnidirectional antenna for WiFi-6 using three dipole patches, a CPW feed, and dual L-shaped coils to achieve stable gain and broad bandwidth**[9]**.
[5]	Microstrip and Printed Antenna Design	Randy Bancroft	Designing real-world microstrip antennas. It covers key concepts, design techniques, and updates like dual-band and circularly polarized antennas**[10]**.
[6]	A Broadband MIMO Antenna Array for WiFi-6E/7 in Laptop Computer Applications	J. -H. Yang and H. -L. Su	A tri-band antenna design for WiFi6E/7 that improves upon earlier MIMO arrays by enhancing fabrication robustness**[11]**.

Table 1: Literature Review

2.2 Motivation

With the rapid evolution of wireless communication, the demand for faster, more reliable, and broader coverage networks has grown significantly. Wi-Fi 7, as the next-generation standard, promises to meet these demands by operating across multiple frequency bands, including the newly extended 6 GHz range. However, to fully harness its potential, efficient and compact antenna designs are essential. This project is motivated by the need to develop a tri-band omnidirectional antenna that not only supports the full Wi-Fi 7 spectrum but also ensures stable performance, high gain, and ease of integration into modern devices. By addressing these challenges, the proposed design aims to contribute to the advancement of high-speed wireless connectivity in both indoor and outdoor environments.

2.3 Problem Statement & Objectives

2.3.1 Problem Statement

Design and Simulation of Antenna for Wi-Fi System in 2.4GHz and 5-7.125 GHz band and its system level performance characterization.

2.3.2 Objectives

- Design a compact, low cost rectangular Microstrip Patch Antenna using FR4 epoxy substrate.
- Achieve triple band operation by incorporating rectangular slots.
- Enhance bandwidth at lower frequencies using microstrip line feed.
- Optimize antenna parameters to improve performance.
- Simulate the antenna using Ansys HFSS Design 3D Modeler to analyze radiation pattern, gain, reflection coefficient.
- Fabricate and test the antenna to validate simulation result using Vector Network Analyzer.
- Evaluate performance in terms of impedance bandwidth, radiation efficiency, gain across three bands.

2.4 Software tools

- Ansys HFSS Design 3D Modeler
- CAD Software
- Vector Network Analyzer (VNA)

2.5 Thesis Structure

Chapter 1: Introduces the importance of antennas in Wi-Fi 7, outlines the motivation, reviews key antenna concepts, and sets the context for the study.

Chapter 2: Summarizes related research, defines the problem and objectives, lists tools used, and outlines the thesis structure.

Chapter 3: Covers the basics, working, advantages, applications, and feeding methods of microstrip patch antennas.

Chapter 4: Details the antenna design, dimensions, material used, and the HFSS simulation setup.

Chapter 5: Describes antenna fabrication, presents simulation and measured results, and compares both for validation.

CHAPTER III

MICROSTRIP PATCH ANTENNA

3.1 History of Microstrip Patch Antenna

In the 19th century, microwave circuitry began utilizing coaxial cables and twin parallel wire lines as transmission lines. The mid-20th century saw the advent of printed circuit board technology, which enabled the creation of inexpensive and simple printed circuit versions of these transmission lines. The printed circuit version of the two-wire transmission line is known as the Microstrip line, featuring a metallic ground plane as the virtual second conductor. Similarly, the coaxial cable was adapted into a printed circuit version called Strip line.

The potential of microstrip structures as radiators for electromagnetic waves was recognized in the 1950's. In 1953, Deschamps introduced the concept of microstrip radiators **[12]**, and in 1955, Gutton and Baissinot were granted a patent in France **[13][14]**. However, it took about 20 years before a practical microstrip antenna was fabricated. Initially, these microstrip radiators were confined to laboratories due to high losses and poor radiation efficiency, largely because suitable low-loss dielectric materials were not available. During this period, Strip line gained more attention due to its ease of design, analysis, and compatibility with microwave planar structures, as well as its ability to support transverse electromagnetic (TEM) waves **[15]**. In 1955, R. M. Barret noted that the "advantages of strip line and microstrip line are the same as those of coaxial and twin wire transmission lines **[16]**. This similarity might explain why microstrip radiators did not immediately attract significant attention during that time.

Research on microstrip radiators gained momentum when better dielectric materials with improved thermal and mechanical properties and low loss tangents were discovered. In 1969, Denlinger demonstrated that microstrip radiators with rectangular and circular shapes could radiate efficiently **[17]**. He found that if a microstrip line is left open-ended, the discontinuity causes electromagnetic waves to radiate from each open end. The radiation is maximized when these discontinuities are separated by half a wavelength or multiples thereof. Denlinger also noted that increasing the height of the dielectric substrate could enhance radiation efficiency, achieving up to 70% radiation for rectangular microstrip radiators and up to 75% for circular ones. These microstrip radiators were subsequently termed microstrip antennas.

One significant advantage of microstrip antennas is their compatibility with planar and non-

planar surfaces, making them easy to mount. This feature attracted considerable attention in the early 1970's for high-performance applications such as aircraft, spacecraft, missiles, and satellite communications. In 1972, Howell introduced a basic rectangular microstrip antenna fed by a microstrip transmission line. During this period, microstrip antennas became a major focus for researchers, leading to various design innovations. However, achieving high radiation efficiency, limited to about 90 per, and addressing narrow bandwidth issues remained challenging. The research and development of microstrip antennas received a significant boost in 1981 when the IEEE Transactions on Antennas and Propagation dedicated a special issue to them **[18]**.

3.2 Microstrip Antenna

In its simplest form, a microstrip antenna consists of two thin metallic layers (t less than $\lambda 0$, where $\lambda 0$ is wavelength in free space) one serving as the radiating patch and the other as the ground plane, with a dielectric substrate sandwiched between them. The radiating patch, typically made of copper or gold, is placed on top of the dielectric substrate, while the ground plane is on the opposite side. Although the radiating patch can take various shapes, simple geometries like square, rectangular, dipole, triangular, elliptical, and circular are preferred due to their ease of analysis and predictable performance using theoretical models. Circular, rectangular, and dipole shapes are particularly common because they are straightforward to analyze and fabricate. The substrate, which plays a crucial role in the antenna's characteristics, is available in a range of dielectric materials with dielectric constants **[19]**. The substrate height, between $0.003\lambda 0$ and $0.05\lambda 0$ wavelengths, significantly influences the antenna's performance. Microstrip antennas typically have a narrow frequency bandwidth, which can be a drawback. However, they are quite useful for applications that require a narrow bandwidth, such as government security systems. The bandwidth of a microstrip antenna is directly influenced by the height of the substrate. To improve the bandwidth, there are two main approaches: using circuit theory techniques and making structural adjustments.

The performance of an antenna is not just determined by the antenna element itself; it is also affected by the combination of the transmission line (TX-line) and the antenna. This mismatch leads to impedance issues, causing a voltage standing wave pattern on the transmission line, which results in a low impedance bandwidth. To address this problem, impedance

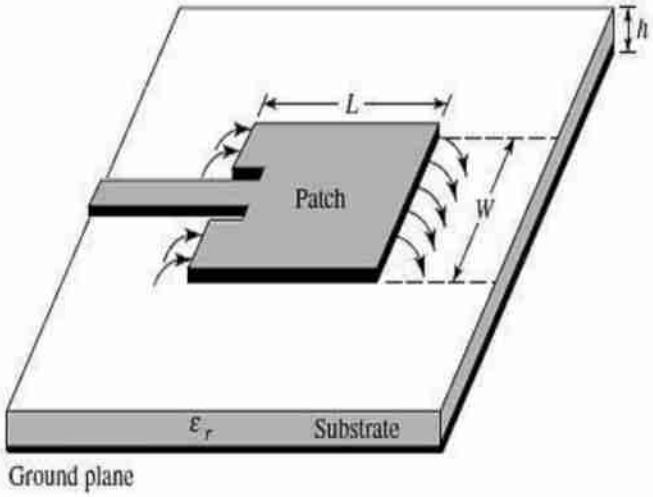


Figure 2.1: Microstrip Patch Antenna

matching networks can be used between the antenna and the transmission line. There are various techniques available for impedance matching, and circuit theory covers these methods. Structural techniques involve modifying the properties of the substrate, such as its height and

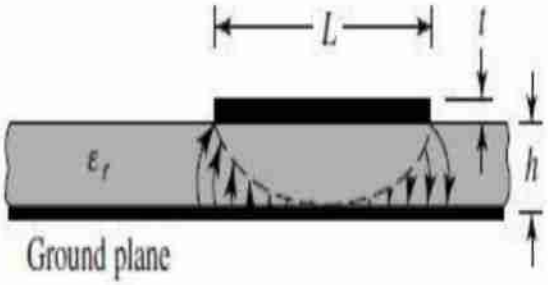


Figure 2.2: Side View of MPA

dielectric constant. Increasing the height can boost the bandwidth, but it also introduces surface waves, which increase power loss and degrade performance. Researchers have explored various methods like stacking, defected ground planes, and parasitic patches to improve the bandwidth of microstrip antennas. This remains a fascinating area of study. By selecting a specific shape, one can design an antenna with the desired resonance frequency, radiation pattern, and polarization. Additionally, it is easy to create a microstrip antenna with reconfigurable polarization, resonance frequency, and radiation patterns by adding components like PIN diodes and varactor diodes.

3.3 Radiation Mechanism

In 1969, Denlinger discovered that when a microstrip line is left open-ended on one side and fed on the other, the discontinuity causes some power to radiate into space from both ends as electromagnetic waves. He found that the radiated power is maximized when the discontinuities are spaced half a wavelength or multiples of half a wavelength apart [6]. Denlinger concluded that radiation occurs from the open end due to fringing fields created by the discontinuity.

To understand the radiation mechanism of a microstrip antenna, imagine a rectangular antenna with a half-wavelength long radiating patch fed by a microstrip feed line. This rectangular antenna can be seen as a microstrip line left open-ended on one side, with energy fed from the other end. Because the patch is half a wavelength long and open-ended on one side, the current is zero at the corners (the beginning and end) and peaks at the center. The current and voltage are 90 degrees out of phase, with the voltage being maximally positive at the beginning and maximally negative at the end of the patch **[20]**.

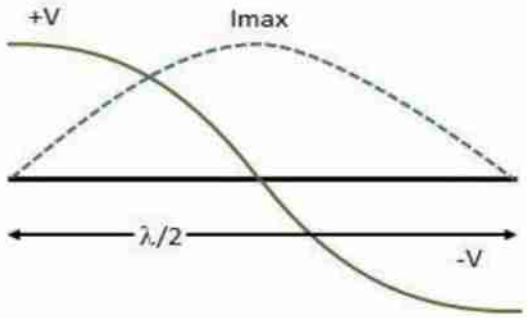


Figure 2.3: Current and Voltage variation along the patch length

The figure below shows the field distribution along the patch. The field lines beneath the patch near the corners run in opposite directions. These field lines do not stop abruptly at the ends; instead, fringing fields are created at the corners, forming bow-shaped lines. The more pronounced these fringing fields are, the greater the radiation. Thus, these fringing fields are responsible for the radiation from the microstrip antenna.

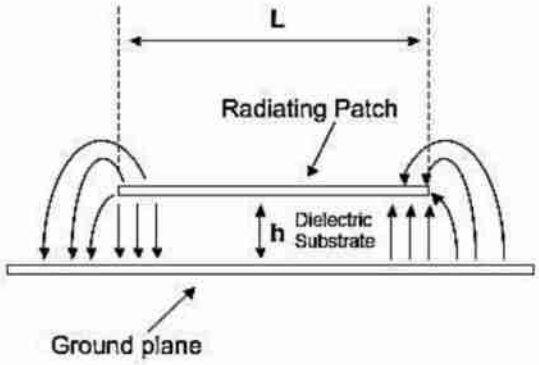


Figure 2.4: Fringing fields

3.4 Advantages and Disadvantages

Microstrip antennas are low-profile, lightweight, and easy to install, making them highly popular in handheld wireless devices like cell phones. They are also widely used in high-performance communication systems, including satellites, missiles, spacecraft, and aircraft. According to experts, some of the key advantages of microstrip antennas include their compact size, ease of fabrication, and versatility in various applications.

1. Lightweight and low profile.
2. Inexpensive and easy to fabricate.
3. Easy to design antenna with desired polarization.
4. Mechanically robust, resistant against vibration and shock.
5. Suitable to microwave integrated circuits (MICs) and monolithic microwave integrated circuits (MMICs).
6. For high gain and directivity array of antennas can be easily formed.

Conversely microstrip antennas also have several disadvantages and limitations when compared to other antennas. Some of the major disadvantages of microstrip antennas are given below:

1. Low gain and power handling capabilities.
2. Suffers from surface wave when high dielectric constant is used.

3. High dielectric and conductor losses.

4. Narrow impedance bandwidth

5. Suffer from spurious feed radiation.

6. Cross polarization.

7. High quality factor.

There are several ways to address these limitations. The bandwidth of a microstrip antenna can be increased using techniques such as defected ground plane strategy, stacked patches, slotted patches, and parasitic patches. The gain and power handling capability of the antenna can be enhanced by creating an antenna array. Additionally, using Electromagnetic Band Gap (EBG) structures and meta-materials can further improve the antenna's characteristics [10].

3.5 Application

Despite their limitations, microstrip antennas are highly valued for their numerous advantages and are widely used in various applications. They are extensively employed in defense systems such as missiles, aircraft, satellites, and rockets. Nowadays, microstrip antennas are also popular in commercial sectors due to their cost-effectiveness and ease of manufacturing, thanks to advanced printed circuit technology. With ongoing research and development, it is anticipated that microstrip antennas will eventually replace many conventional antennas.

1. Mobile Application:

Microstrip antennas are vital for mobile applications because they are lightweight and compact. They are widely used in cell phones, UHF pagers, and radar systems in vehicles like cars, planes, and ships. These antennas are also crucial for 5G technology, enabling faster data transmission, and are found in wearable devices such as smartwatches and fitness trackers. Their versatility and efficiency make them an essential part of today's mobile technology.

2. Satellite Communication

In satellite communication, antennas need to have circular polarization to ensure efficient

signal transmission and reception. One major advantage of microstrip antennas is their ability to be easily designed with the required polarization using dual feed networks and various techniques. While parabolic antennas are traditionally used for broadcasting from satellites due to their high gain and directivity, flat microstrip antenna arrays can serve as an alternative to parabolic reflectors. These arrays offer benefits such as lower weight and volume, making them suitable for space applications.

3. Global Positioning System

Microstrip patch antennas are essential in GPS systems due to their compact size and ease of integration. They are used in various applications, including automotive navigation, aviation, marine navigation, portable devices, and wearable technology. These antennas provide reliable performance and accurate location tracking, making them ideal for use in cars, aircraft, ships, handheld GPS devices, and smartwatches. Their lightweight and low-profile design allow them to be seamlessly incorporated into different devices, ensuring precise positioning and navigation.

4. Direct Broadcast Satellite System

In many countries, direct broadcasting systems are used to provide television services. Typically, users need a high-gain antenna (around 33 dB) on the ground. Parabolic reflector antennas are commonly used, but they are bulky, require a lot of space, and can be affected by snow and rain. Instead, an array of circularly polarized microstrip antennas can be used for direct broadcasting reception. These antennas are easier to install, less affected by weather conditions, and more affordable.

5. Radar Application

Radar applications like Man pack radar, Marine radar, and Secondary surveillance radar need antennas with the right gain and beam width. An array of microstrip antennas can be designed to meet these requirements. For tasks such as sensing ocean wave speed and direction or determining ground soil grades, Synthetic Aperture Radar (SAR) is used. This system employs two arrays of patch antennas placed at a specific distance from each other.

6. Medical Science

In medical science, microwave energy is increasingly used to treat malignant tumors by inducing hyperthermia. Recent studies highlight the effectiveness of microwave ablation (MWA) as a non-invasive method for eradicating tumors, particularly in the liver. For instance, a 150-watt microwave ablation system has shown improved tumor control and reduced local treatment failures. This system can heat tissues more evenly, which makes it better at destroying tumors. Additionally, MWA has been found to offer better survival rates and lower recurrence rates for hepatic malignant tumors. Microstrip patch antennas, such as annular ring and circular disk types, remain ideal for these applications due to their adaptability to the surface being treated and lightweight design. Flexible patch monopole microstrip applicators are particularly useful for conforming to curved surfaces during treatment.

3.6 Feeding Techniques

There are many ways to feed a microstrip antenna, each with its own pros and cons. Choosing the right feeding technique depends on several factors, with the main goal being efficient power transfer from the feed line to the antenna's radiating element. Proper matching between the feed and the antenna is crucial, and techniques like impedance transformers and stubs are used for this purpose. The feed structure should be easy to fabricate along with the radiating element.

3.6.1 Microstrip Line Feeding

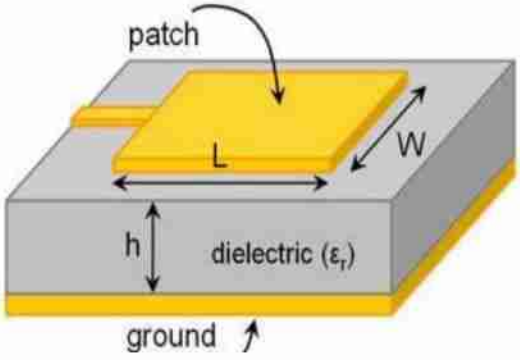


Figure 2.5: Microstrip line feeding

In this feeding method, the radiating patch is directly fed by a microstrip feed line, which is narrower than the patch. This is a simple and commonly used technique because the

microstrip line can be considered an extension of the radiating patch and is fabricated on the same substrate. It is easy to make, and impedance matching techniques work well with it. However, this method has some drawbacks, including spurious feed radiation, surface wave losses, and low bandwidth. Recent research has focused on improving these issues by optimizing the design and materials used in the microstrip feed line.

3.6.2 Coaxial Probe Feed

Coaxial cable feeding is one of the most widely used methods for powering microstrip antennas. In this setup, the inner conductor of the coaxial cable is soldered directly to the patch, while the outer conductor is connected to the ground plane. The cable's core passes through a hole in the substrate to reach the patch. One of the biggest advantages of this method is that it provides a straightforward way to match the antenna's input impedance with the cable's characteristic impedance. Recently, researchers have been working on refining this technique to minimize unwanted radiation and boost bandwidth.

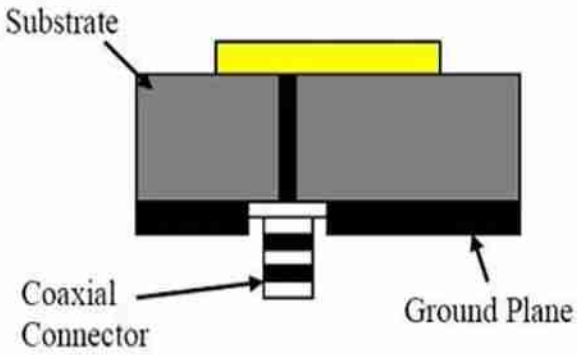


Figure 2.6: Coaxial Probe Feed

3.6.3 Proximity Couple Feed

This feeding technique uses two different dielectric layers. Instead of connecting the microstrip line directly to the patch, the line is left open at the end and placed between the two substrates. The energy is transferred to the patch through electromagnetic coupling. By extending the microstrip line into a stub, the antenna's bandwidth can be improved. The choice of materials is important: a thick upper layer with a low dielectric constant helps boost the fringing fields and radiation, while a thin lower layer with a high dielectric constant helps reduce unwanted feed radiation. This method offers the widest bandwidth among common

feeding techniques and is relatively simple to model. However, it does require precise alignment during fabrication, which can be a bit tricky. Adjusting the stub length and the patch's width-to-line ratio allows fine-tuning of the antenna's performance.

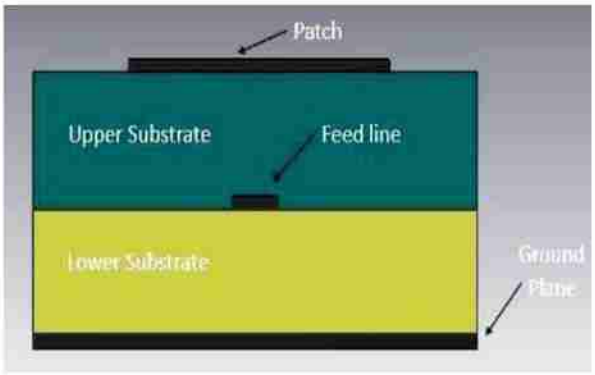


Figure 2.7: Proximity couple feed

3.6.4 Aperture Couple Feed

The structural view of this feeding method is shown in the figure. It uses two types of substrates with a ground plane placed between them. The microstrip line, typically used for feeding, is positioned below the lower substrate. In aperture coupling, the patch antenna gets its energy through a small opening or slot in the ground layer, kind of like passing a signal through a window. Different aperture shapes are used, with rectangular and circular ones being the most common. Cross-shaped and annular ring slots are used to achieve circular polarization.

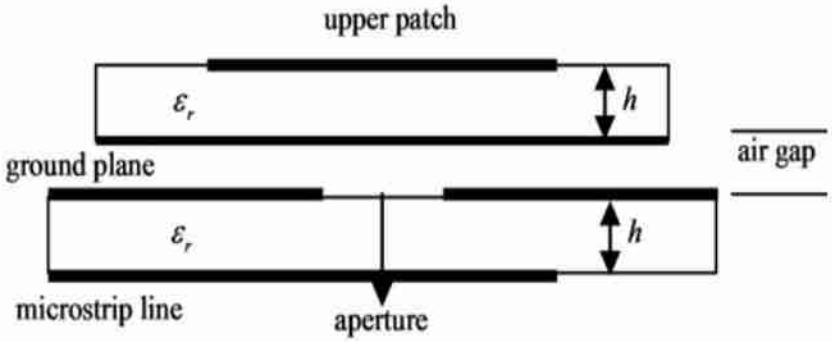


Figure 2.8: Aperture Couple Feed

The slot settings are fine-tuned to help the antenna work better and boost its overall performance. Like proximity coupled feeding, the dielectric constants of the substrates are chosen to optimize radiation and bandwidth. A thick material with a low dielectric constant is used

for the top layer to boost radiation and bandwidth, while a thin material with a high dielectric constant is used for the bottom layer to ensure efficient energy transfer from the feed line to the patch. To get the best coupling between the feed structure and the patch, the slot should be placed where the magnetic field is the strongest**[21]**. From the current and voltage distribution along the patch, we know that the electric field is strongest at the ends, and the magnetic field is strongest in the center. The microstrip feed line is extended to create a stub, which behaves like an open-ended transmission line. This stub introduces an admittance that appears in parallel with the slot.. By adjusting the stub length, the slot's reactive components can be neutralized, resulting in improved impedance matching.

CHAPTER IV

DESIGN SPECIFICATION

4.1 Antenna Design Specification

This chapter presents the design, simulation, and performance analysis of a tri-band planar antenna intended for integration into compact wireless devices such as WiFi routers, IoT modules, and chip sets. The antenna is designed to deliver high-efficiency performance across the 2.4 GHz ISM band and the extended 5 GHz to 7.125 GHz frequency range, thereby supporting WiFi standards including 802.11ac (WiFi 5), 802.11ax (WiFi 6/6E), and 802.11be (WiFi 7).The antenna is fabricated on a rectangular dielectric substrate (green in the image), with copper traces (orange) forming the radiating structure. The geometry is segmented into multiple regions and triangular stubs, each contributing to resonance at different frequency bands.

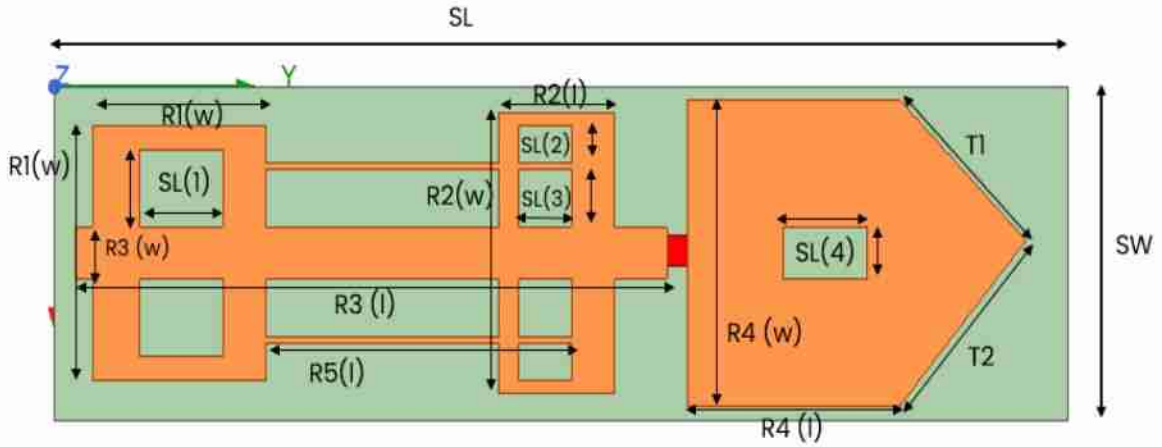


Figure 4.1: Dimension of the Proposed Antenna Design

The antenna is fabricated on a rectangular dielectric substrate with a microstrip-fed radiating structure. The design incorporates multiple resonating sections and triangular stubs to achieve tri-band operation. The radiating patch is composed of three main rectangular sections and triangular stubs, each contributing to specific resonant frequencies.The triangular stubs (T1, T2) are strategically placed at the ends of the resonators to introduce capacitive loading, which enhances bandwidth and improves impedance matching.

4.1.1 Dimensions of Antenna

All the dimensions can be seen in following table:

Parameter	**Values**
Substrate length (S_l)	52mm
Substrate width (S_w)	13mm
First Rectangle $(R1_l)$	8.2mm
First Rectangle $(R1_w)$	10mm
Second Rectangle $(R2_l)$	5.5mm
Second Rectangle $(R2_w)$	11mm
Third Rectangle $(R3_l)$	28mm
Third Rectangle $(R3_w)$	2mm
Fourth Rectangle $(R4_l)$	10mm
Fourth Rectangle $(R4_w)$	12mm
Fifth Rectangle $(R5_l)$	11mm
Fifth Rectangle $(R5_w)$	0.2mm
Triangle Side $(T1)$	5.5mm
Triangle Side $(T2)$	6mm
Slot 1 $(Sl(1)$	4l X 3w
Slot 2 $(Sl(2)$	2.5l X 1.5w
Slot 3 $(Sl(3)$	2.5l X 2.3w
Slot 4 $(Sl(4)$	4l X 2w

Table 2: Dimensions of Proposed Antenna Design

In this project, a high-frequency structure was designed using a rectangular substrate modeled in ANSYS HFSS, serving as the foundational layer that significantly influences the electromagnetic behavior of the system. The substrate, made of FR-4 epoxy, was selected for its favorable dielectric properties, including a relative permittivity (r) of 4.4, a low loss tangent of 0.02, and good thermal stability. With dimensions of 52 mm in length, 13 mm in width, and a thickness of 1.6 mm, the substrate was carefully dimensioned to balance mechanical strength and electrical performance, ensuring minimal signal attenuation and effective impedance matching.

On top of this dielectric layer, a rectangular copper patch—chosen for its excellent electrical conductivity and standard PCB compatibility—was designed as the radiating element. The copper layer had a thickness of 0.1 mm and was precisely placed on the substrate's top surface. Its dimensions were calculated based on the desired resonant frequency and the

substrate's dielectric characteristics, ensuring accurate electromagnetic interaction within the HFSS simulation environment.

4.2 Software based Design Validation

The theoretical modeling, simulation parameters, boundary conditions, and software tools used to design and analyze the system. It includes:

4.2.1 Simulation Environment Setup

ANSYS HFSS (High Frequency Structure Simulator) is a leading 3D full-wave electromagnetic simulation tool based on the Finite Element Method (FEM), widely used for designing RF, microwave, antenna, and high-speed digital components. In this project, HFSS was utilized to analyze and optimize the high-frequency structure, enabling accurate computation of S-parameters, impedance matching, radiation patterns, and field distributions. The design process began with creating a new project, using the Project Manager to organize the model hierarchy, the Properties window to assign materials and dimensions, and the Draw toolbar to construct the antenna geometry. Real-time feedback was provided through the Progress and Message Manager, while the Results section offered detailed visualizations of performance metrics such as gain, VSWR, and radiation patterns. HFSS's validation and optimization features ensured the design met all performance specifications before fabrication.

4.2.2 Boundary Condition

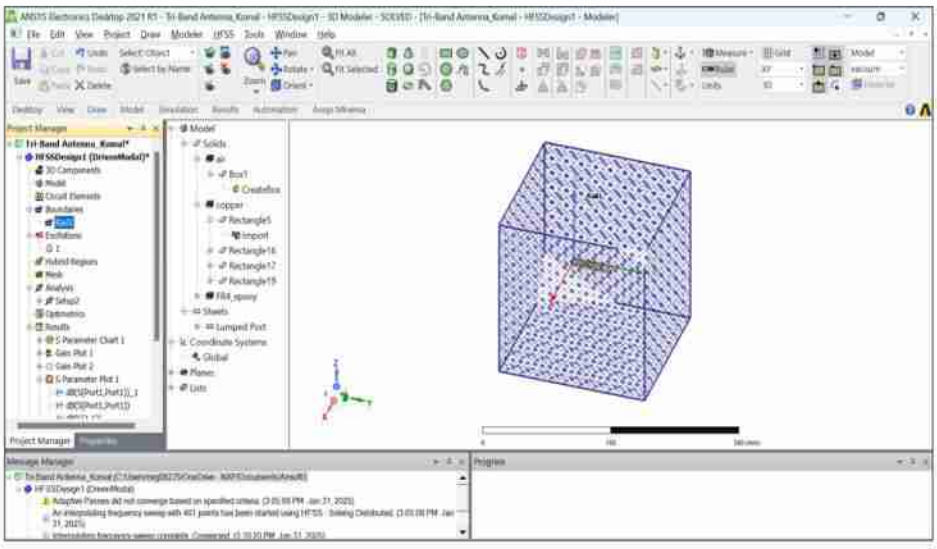


Figure 4.2: HFSS Interface showing boundary condition

Importance of Boundary Conditions Boundary conditions are essential in electromagnetic simulations to define how the fields behave at the edges of the simulation domain. In HFSS, they help mimic the real-world environment and ensure accurate field solutions. Common boundary conditions include:

- Radiation Boundary: Simulates open space, allowing electromagnetic waves to radiate outward without reflection.
- Perfect Electric Conductor (PEC): Used for metallic surfaces like the copper patch.
- Perfectly Matched Layer (PML): An advanced absorbing boundary that minimizes reflections at the domain edges.

4.2.3 Solution Setup

The Solution Setup window in ANSYS HFSS is where the simulation parameters are defined. This includes:

- Frequency Sweep: Specifies the range of frequencies over which the simulation is performed (e.g., 2 GHz to 8 GHz).
- Maximum Number of Passes: Controls how many adaptive passes the solver will perform to refine the mesh and improve accuracy.
- Convergence Criteria: Defines the threshold for acceptable error between passes.
- Solver Type: Typically set to Driven Modal for S-parameter analysis in high-frequency structures.
- Port Setup: Ensures that excitations are correctly defined for signal input and output.

This setup ensures that the simulation runs efficiently while maintaining high accuracy in the results.

CHAPTER V

ANTENNA FABRICATION, OPERATION AND SIMULATION RESULTS

5.1 Antenna Fabrication

The fabrication of antennas on FR-4 substrates using printed circuit board (PCB) technology involves a series of well-defined steps to ensure reliable performance in high-frequency applications. FR-4, a glass-reinforced epoxy laminate, is commonly selected due to its favorable dielectric properties, mechanical robustness, and cost-effectiveness.

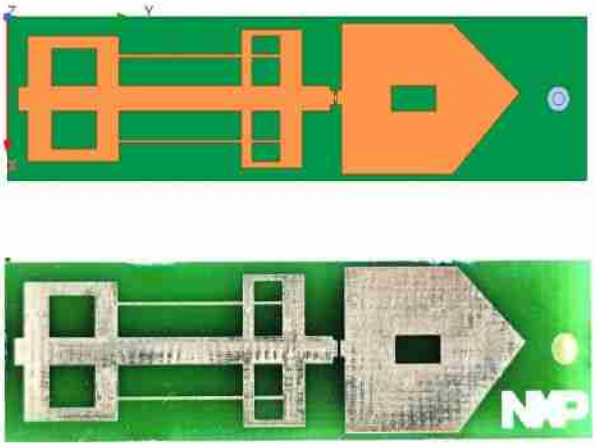


Figure 5.1: Structure of Designed Antenna

The process begins with a copper-clad FR-4 sheet, onto which the antenna layout is designed using computer-aided design (CAD) tools. This design is then transferred onto the copper surface through photolithography or direct etching methods, selectively removing unwanted copper to form the desired antenna geometry. Subsequent fabrication steps may include drilling, plating, and application of solder masks, depending on the complexity of the design. The completed antenna structure is then subjected to inspection and testing to verify its electrical characteristics, such as impedance matching and resonant frequency, ensuring it meets the performance criteria for integration into RF and wireless communication systems.

5.2 Simulation Results

The return loss (S11) plot illustrates how effectively the antenna is matched to the transmission line across a frequency range of 0 to 8 GHz. The simulation was performed using ANSYS HFSS, and the data corresponds to Setup1: Sweep for the parameter dB (S (1,1)), which represents the reflection coefficient in decibels.

Return loss is a key parameter in antenna design that quantifies how much power is reflected back from the antenna due to impedance mismatch between the transmission line and

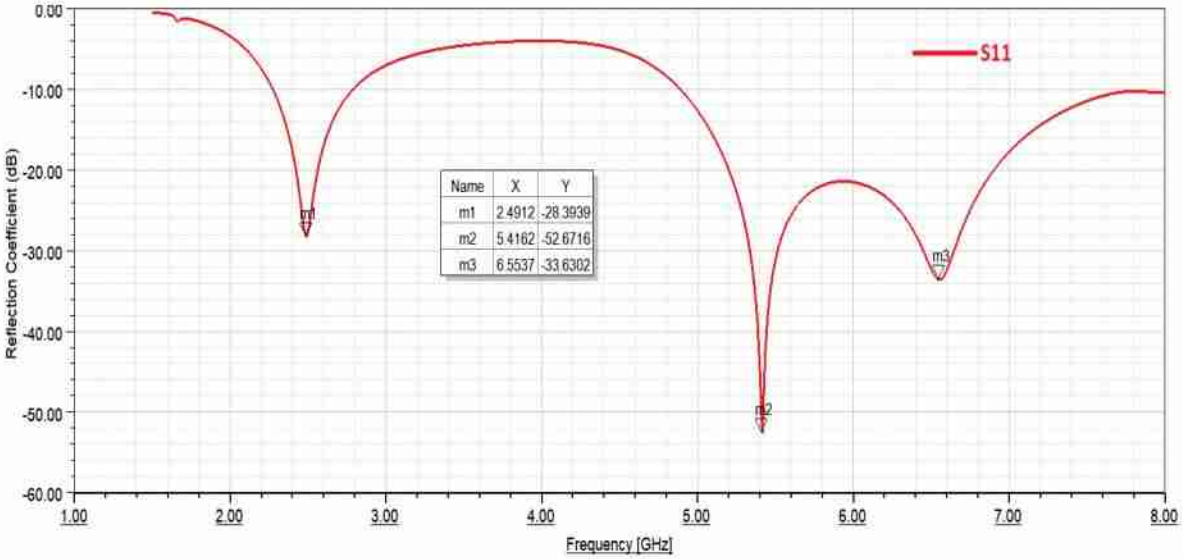
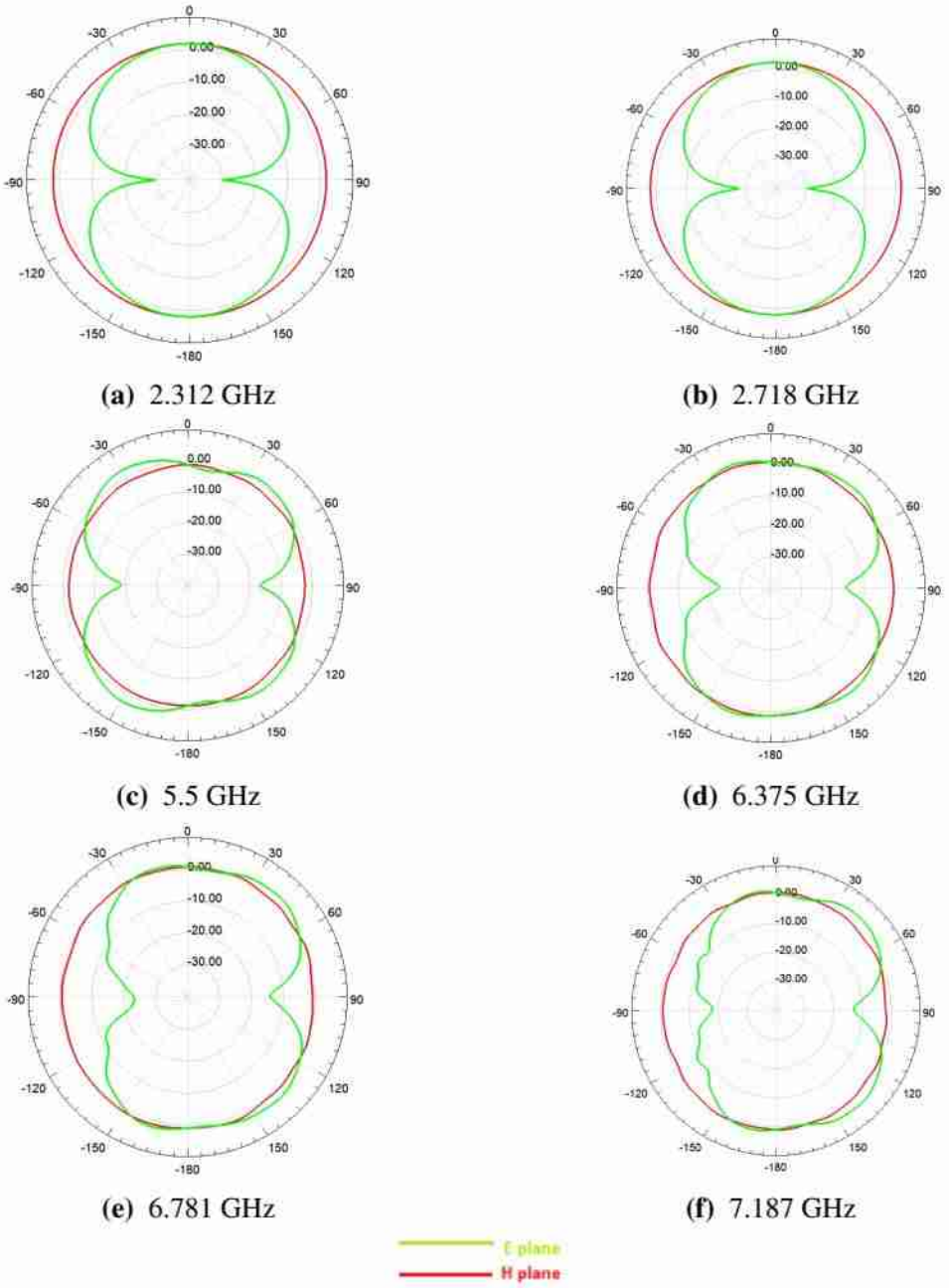


Figure 5.2: Simulated Reflection Coefficient

the antenna. It is expressed in decibels (dB), where a more negative value indicates better impedance matching and less reflected power.The return loss of the designed antenna was measured over a frequency range of 2.27 GHz to 2.79 GHz. The simulation results show a minimum return loss of -28.39 dB, indicating excellent impedance matching at the resonant frequency. Additionally, the antenna exhibited strong performance in higher frequency bands, with a return loss of -52.67 dB at 5.4 GHz and -33.63 dB at 6.5 GHz, both of which reflect superior impedance matching and minimal reflected power. These results confirm that the antenna is well-optimized for multi-band operation, making it suitable for applications requiring high efficiency and wide band performance.

The figures below showing the antenna radiation pattern with principal E-plane and H-plane for different frequencies.



(a) 2.312 GHz **(b)** 2.718 GHz

(c) 5.5 GHz **(d)** 6.375 GHz

(e) 6.781 GHz **(f)** 7.187 GHz

Figure 5.3: Simulated 2D Radiation Pattern

We can observe that the H-Plane patterns are omnidirectional and the E-Plane patterns are have dumble shape pattern.

The VSWR vs. Frequency plot gives a clear picture of how well the antenna is matched across different frequencies. Ideally, a VSWR close to 1 means perfect matching, and anything below 2 is generally good. In this case, the antenna performs best at 7.0 GHz with a VSWR of 1.92, showing strong impedance matching. It also does reasonably well at 2.0 GHz with a VSWR of 2.36. However, performance drops at 3.0 GHz and 5.0 GHz, where the

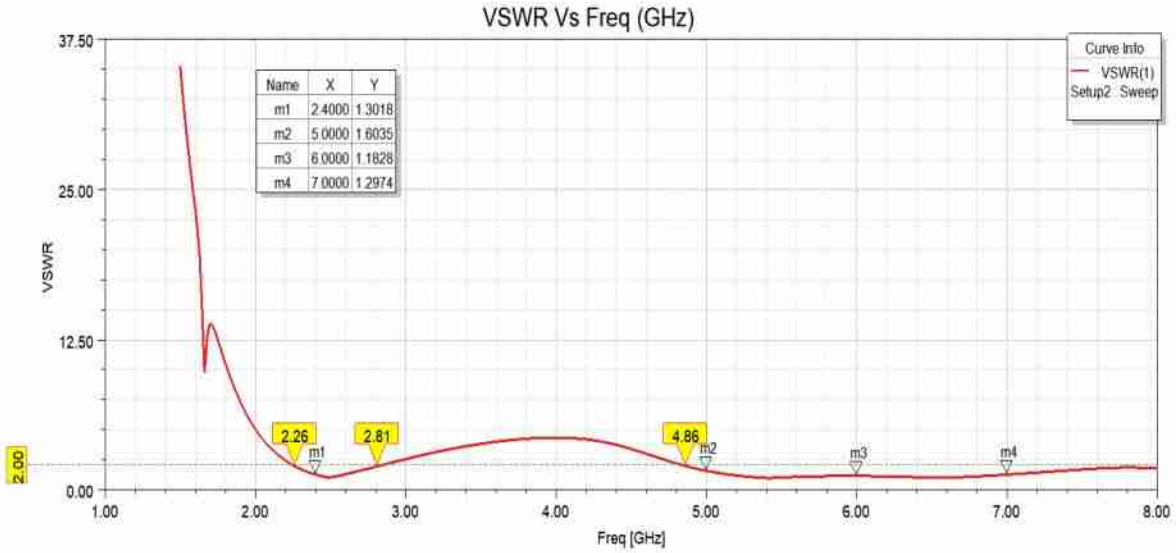
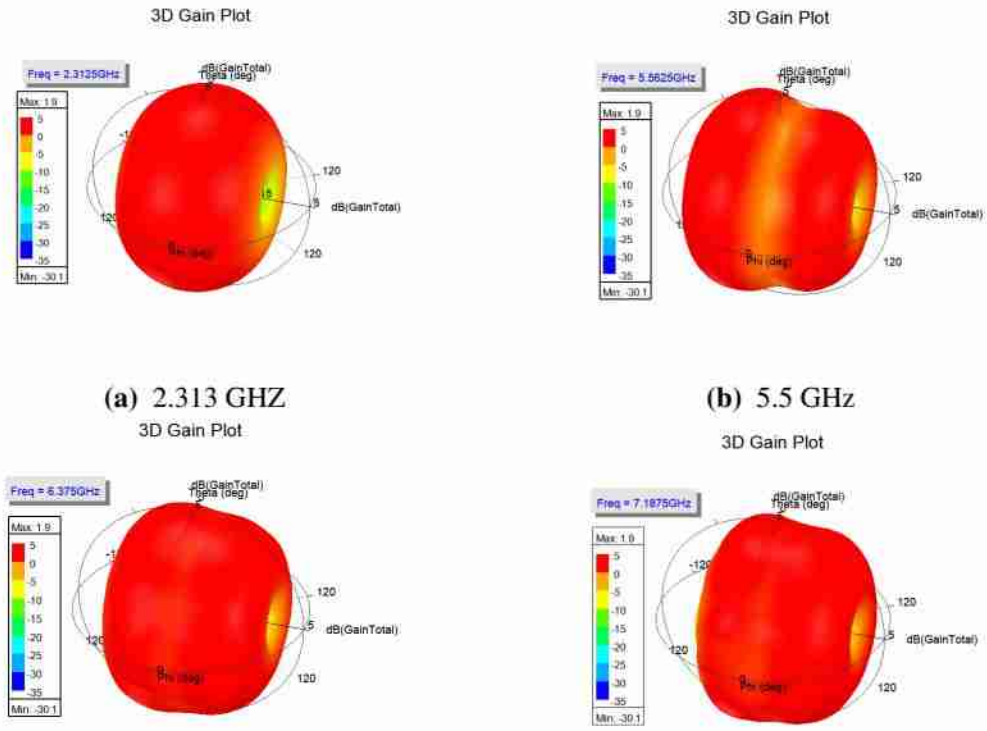


Figure 5.4: VSWR Vs Frequency (GHz) Plot

VSWR rises to 2.81 and 4.86, indicating higher reflection and poorer matching. These results highlight the antenna's strengths and suggest areas for improvement in the mid-frequency range.



(a) 2.313 GHZ **(b)** 5.5 GHz

(c) 6.375 GHz **(d)** 7.187 GHz

Figure 5.5: 3D radiation pattern showing gain (dB)

5.3 Measured Result & Comparison

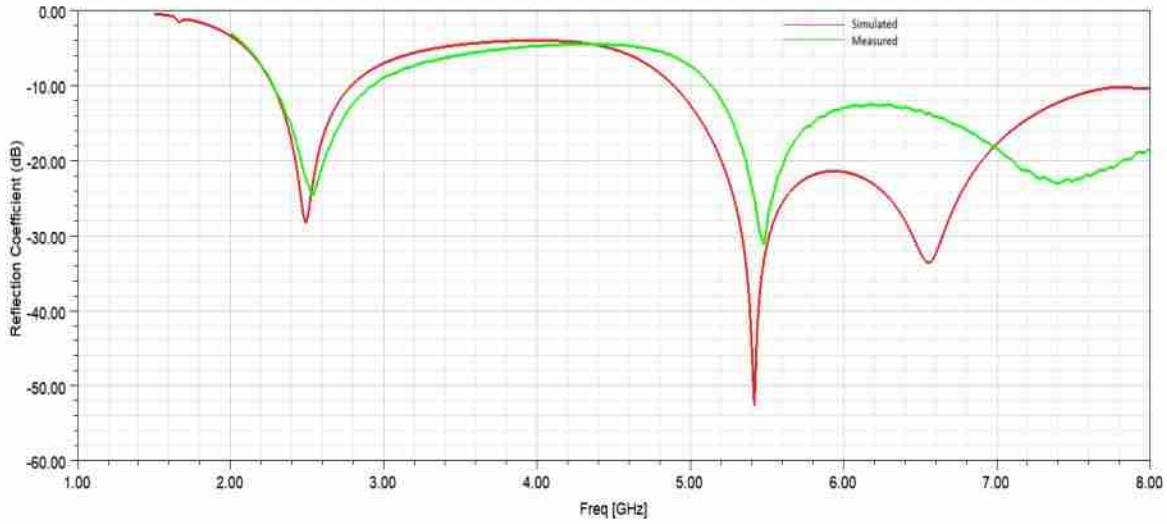


Figure 5.6: Measured and Simulated S-parameters for the proposed designed antenna

After completing the simulation phase using HFSS, the antenna was fabricated using FR-4 substrate material with dimensions of 52 mm × 13 mm × 1.6 mm. The performance of the fabricated antenna was then evaluated using a Vector Network Analyzer (VNA) to obtain the S11 (reflection coefficient) parameters. The comparison between the simulated and measured S11 values is shown in Figure 5.6.

Band	**Simulated S11 (dB)**	**Measured S11 (dB)**
2.4 GHz	-28.39	-24.81
5.4 GHz	-52.67	-31.29
6.5 GHz	-33.63	-13

Table 2: Compared simulated and measured S11

Despite minor deviations in the higher frequency bands, the measured results validate the simulated design. The fabricated antenna effectively covers the target tri-band frequencies (2.4 GHz, 5–6 GHz, and 6–7.125 GHz) with S11 ¡ –10 dB, confirming practical usability in Wi-Fi 7 applications. The alignment in resonance trends between simulation and measurement demonstrates that the proposed design is robust and manufacturer with minor tuning.

CHAPTER VI

CONCLUSION

Conclusion

A compact, tri-band omnidirectional antenna for Wi-Fi 7 has been successfully designed and simulated. The antenna demonstrates excellent impedance matching, gain, and radiation characteristics, confirming its suitability for next-generation wireless routers. Compared to existing designs, it offers a balanced trade-off between performance and fabrication simplicity.

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